

COMPTEL OBSERVATIONS OF ACTIVE GALACTIC NUCLEI

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ABSTRACT

The number of AGN's that might be observed by COMPTEL around 1 MeV is of the order of two dozens or less. The estimate is based on the HEAO-1 measurements between 2 keV and 100 keV and on the assumption that the power law spectra of AGN's at X-ray energies extend to at most 3 MeV before they break off.

I. INTRODUCTION

Active Galactic Nuclei belong - among others - to the most interesting objects in the sky. The engine in the center that powers these galaxies is not yet really known. Most people tend to believe that a massive black hole is somehow involved.

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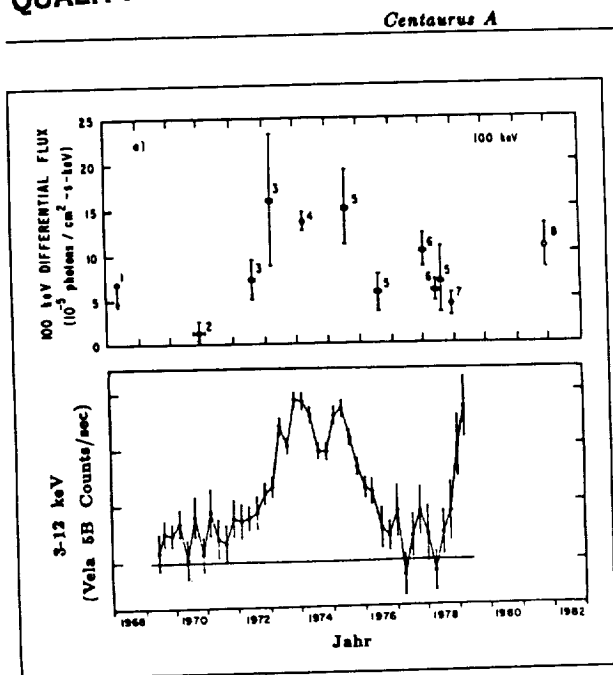


Figure 1. Time variation of the Centaurus X-ray flux at 100 keV (top) and between 3 to 12 keV (bottom). Compilation of measurements adopted from v. Ballmoos (1985).

At least some of the AGN's do have their absolute maximum of luminosity at MeV gamma ray energies. Therefore, it is reasonable to speculate that the key for an understanding of the central energy source may be found at MeV gamma ray energies. In this short talk I want to address the capabilities of COMPTEL to observe AGN's. The two most outstanding features of AGN's at gamma ray energies are their "time variability" and their "power law energy spectra" over a broad spectral range with a break or even cut off at MeV-energies or somewhere below. Both these features are illustrated in figures 1 and 2.

Figure 1 shows the time variability of the soft and hard X-ray emission of the radio galaxy Cen A. Here the 3 to 12 keV and the 100 keV flux is plotted over a time interval of more than 10 years. Clearly, the luminosity of Cen A has changed by more than a factor of 4 within - say 1 year. If therefore, comparisons between observations of one and the same object with different instruments in different spectral ranges are made, it is essential that these observations are performed simultaneously. The shortest time variabilities that have been observed from AGN's constrain the size of the central energy source to less than about 10^{15} cm.

The power law shape of the energy spectra of AGN's over wide spectral ranges is illustrated on figure 2, which shows the spectrum of the quasar 3C 273 from radio to gamma ray energies. The spectrum is an eye fit to the existing measurements. The fit is based on 4 power law components and two blackbody components in the visible and in the UV. In a crude sense the energy spectra of other AGN's like Seyferts, radio galaxies and BL Lac's look similar, though there are of course certain differences.

If the energy spectrum of figure 2 is converted into a luminosity spectrum, then it becomes evident that the maximum of luminosity is located near 10^{20} Hz, corresponding to a photon energy of a few MeV. The bending of the power law energy spectrum, which leads to this maximum, must exist for the majority of AGN's either around 3 MeV or at somewhat lower energies in order not to be in conflict with the observations of the gamma ray background (e.g. Rothschild et al., 1983).

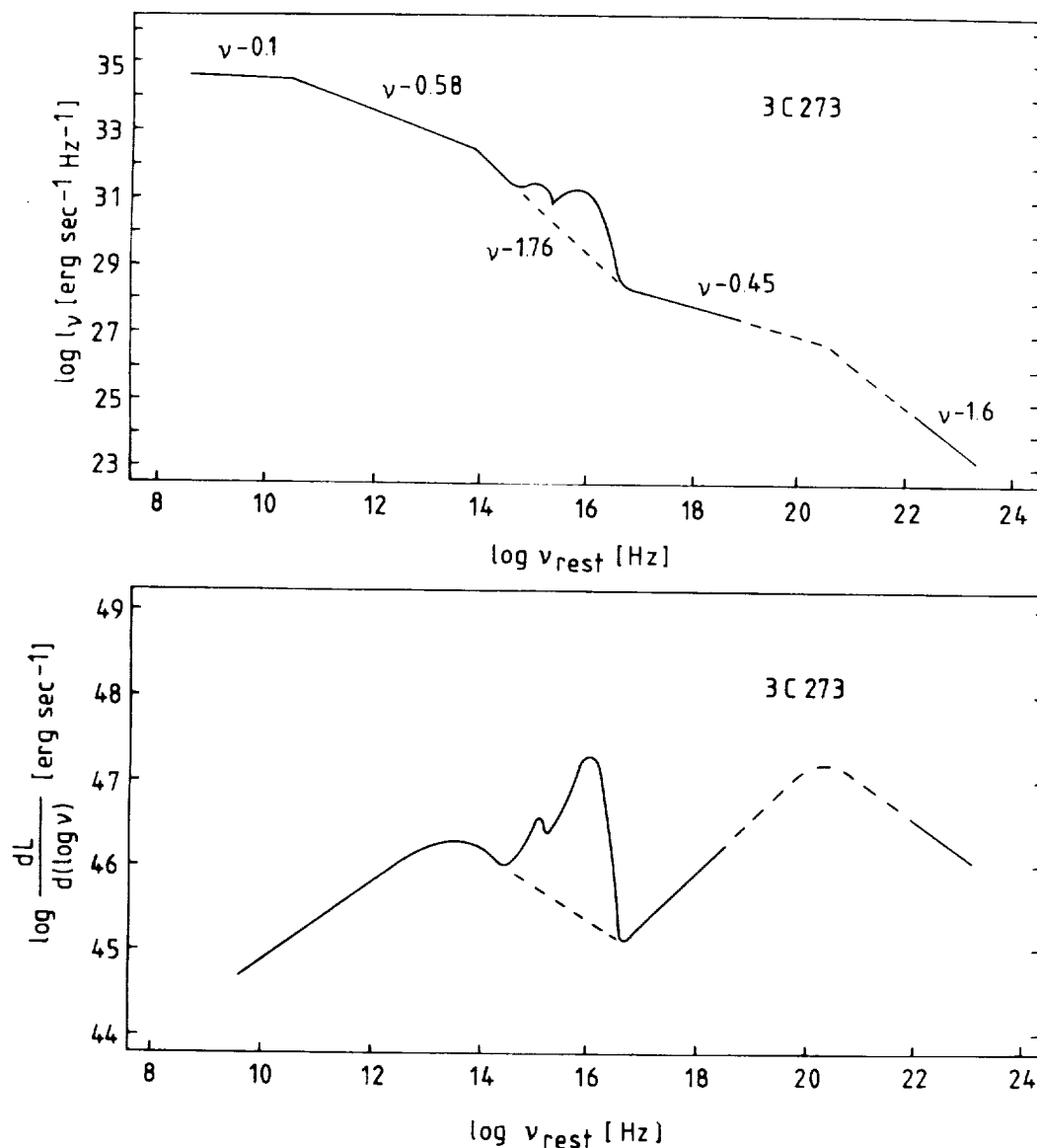


Figure 2. Eye fit to measurements of the quasar 3C 273 from radio to gamma ray energies (adopted from Courvoisier et al., 1987).

Various possibilities exist to explain the bending. The break may simply reflect thermal emission with kT-values of the order 1 MeV, or in case of non-thermal emission (as in case of 3C 273) it may be caused by a cut off of the relativistic electron spectra (due to energy losses), or due to photon - photon absorption in the high photon density field as a necessary consequence of the compactness of the source, or due to the Penrose Compton process.

So far observations of gamma ray emission have been reported from only 5 different objects. These are the Seyfert galaxies NGC 4151 and MCG 8-11-11, the radio galaxy Cen A, the quasar 3C 273, and NGC 1275, the radio galaxy within the core of the Perseus cluster.

NGC 4151 seems to be highly variable at MeV-energies. Only 2 positive detections have been reported above 1 MeV by the MISO-group. Some of the upper limits of other observations (at other times) to the MeV-flux were about 10-times lower than the reported MISO-fluxes (see Bazzano et al., 1989). MCG 8-11-11 is known to be a highly variable Seyfert I galaxy at low X-ray energies. A positive detection of this object at MeV energies by the same MISO instrument showed a flux and a spectral shape similar to those found for NGC 4151 (Bazzano et al., 1989). Cen A is a very strong X-ray source with a power law energy spectrum which well extends into the MeV-range. The gamma ray spectrum must steepen at about 10 MeV (or somewhat below) in order not to be in conflict with upper flux limits set by SAS-2 and COS-B above 35 MeV or 50 MeV, respectively (see v. Ballmoos et al., 1987). 3C 273 at present is the only extragalactic object observed at high gamma ray energies. Interpolation between existing X-ray and γ -ray measurements suggest that 3C 273 has its maximum of luminosity at 2 to 3 MeV (see figure 2 and Hermsen et al., 1981, and Bezler et al., 1984). Strong and Bignami (1983) report a possible detection of gamma ray emission by COS-B from NGC 1275. The excess of gamma ray counts at the position of the galaxy is only marginal.

II. COMPTEL OBSERVATIONS OF AGN'S

COMPTEL's nominal energy range is 1 to 30 MeV. The actual energy threshold will be at 550 keV. COMPTEL has a large field-of-view of about 1 steradian and an angular resolution of (2 to 5) degree FWHM within that field-of-view. The sensitivity of COMPTEL to observe gamma ray emission from AGN's in a two week observation period is illustrated in figure 3. Here the 3σ - sensitivity limits are compared with several reference spectra (Cen A, 3C 273, and 12 AGN's observed by HEAO-1(A4) between 10 keV and 100 keV). The 12 AGN's (mostly Seyferts) observed by HEAO-1 were not the result of a survey, but were the brightest high latitude sources identified with AGN'S before the launch of HEAO-1 (Rothschild et al., 1983). They are listed in Table 1.

TABLE I
12 AGN'S OBSERVED BY HEAO-1 (A4)

NGC 4151	Seyfert I
NGC 1275	Seyfert I in Perseus
MCG 5-23-16	Seyfert II
MKN 509	Seyfert I
NGC 5548	Seyfert I
NGC 6814	Seyfert I
NGC 3783	Seyfert I
3C 390.3	Seyfert I
3C 120	Seyfert I
ESO 141-G55	Seyfert I
MKN 279	Seyfert I
MKN 335	Seyfert I

All 12 AGN's can be fitted by power law spectra with a photon number spectral index of -1.62 between 2 and 165 keV. The galaxy to galaxy variation of the spectral index was found to be less than 0.15. The detectability of these 12 AGN's by COMPTEL will depend on how the spectra continue towards higher energies. If they have spectra similar to 3C 273 or Cen A, then COMPTEL may be able to observe all of them.

The total number of AGN's that might be detected by COMPTEL during the GRO survey in the first year of the mission can be estimated in the following way: above the HEAO-1 (A2) sensitivity limit of 3.1×10^{-11} erg/cm² sec, the complete sky survey of this instrument in the 2 to 10 keV range contained 30 objects with latitudes $|b| > 20^\circ$ (corresponding to 8.2 ster): 25 of them were Seyferts, 4 were BL Lac's and 1 a quasar. The log N - log S relationship of these 30 objects was consistent with an Euclidian one (Picinotti et al., 1982):

$$N(>S) = a S^{-1.5} \text{ ster}^{-1}$$

For $N(> 3.1 \cdot 10^{-11} \text{ erg/cm}^2 \text{ sec}) = 30$ per 8.2 ster we obtain $a = 0.63 \cdot 10^{-15}$.

Under the optimistic assumption that all 30 objects have power law spectra up to 3 MeV with the same spectral photon number index of -1.62 as that found by HEAO-1 (A4) for the 12 AGN's the following estimate can be made:

The derived log N - log S relationship for the 600 keV to 3 MeV range is

$$N(>S) = 0.63 \cdot 10^{-15} \cdot 300^{+0.38} S^{-1.5} \text{ ster}^{-1}$$

Since COMPTEL's (0.6 to 3) MeV sensitivity limit for a two week observation period ($5 \cdot 10^5$ sec) is $1.8 \cdot 10^{-10}$ erg/cm² sec, one obtains

$$N(> S_{\min}) = \begin{cases} 30 \text{ objects over } 4\pi\text{-sky} \\ 20 \text{ objects for } |b| > 20^\circ \end{cases}$$

We therefore can expect that COMPTEL will observe about 2 dozens of AGN's, if they all have power law spectra up to at least 3 MeV. If some spectra break off earlier, the number will be smaller.

In case of a positive detection of a larger number of AGN's, it will be possible to derive their luminosity function at gamma ray energies. The luminosity function together with the measured properties of individual galaxies may lead to a better understanding of the central source of AGN's. The knowledge of the luminosity function will allow a realistic estimate of the contribution of unresolved AGN's to the cosmic gamma ray background.

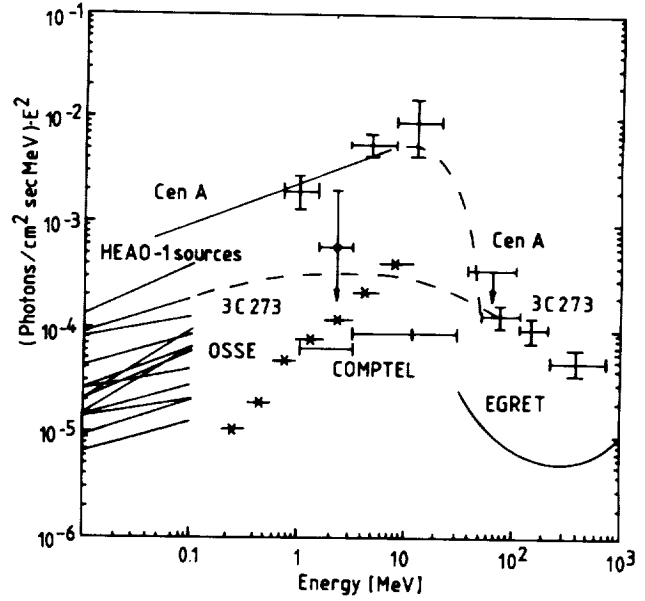


Figure 3. 3σ sensitivity ($5 \cdot 10^5$ sec observation time) of COMPTEL for observation of AGN's.

Table 2 contains a list of AGN's which we consider to be the 16 most promising ones to be studied by COMPTEL.

TABLE II
AGN-CANDIDATES FOR COMPTEL OBSERVATIONS

<u>Seyfert I galaxies:</u>	3C 120, MCG 8-11-11, NGC 3783, NGC 4151, NGC 5548, 3C390.3, NGC 6814, MRK 509
<u>Seyfert II galaxies:</u>	MCG 5-23-16
<u>Quasars:</u>	3C 273
<u>Bl-Lac objects:</u>	MRK 421, MRK 501
<u>Radio galaxies:</u>	NGC 1275, M 87, Cen A, Cyg A

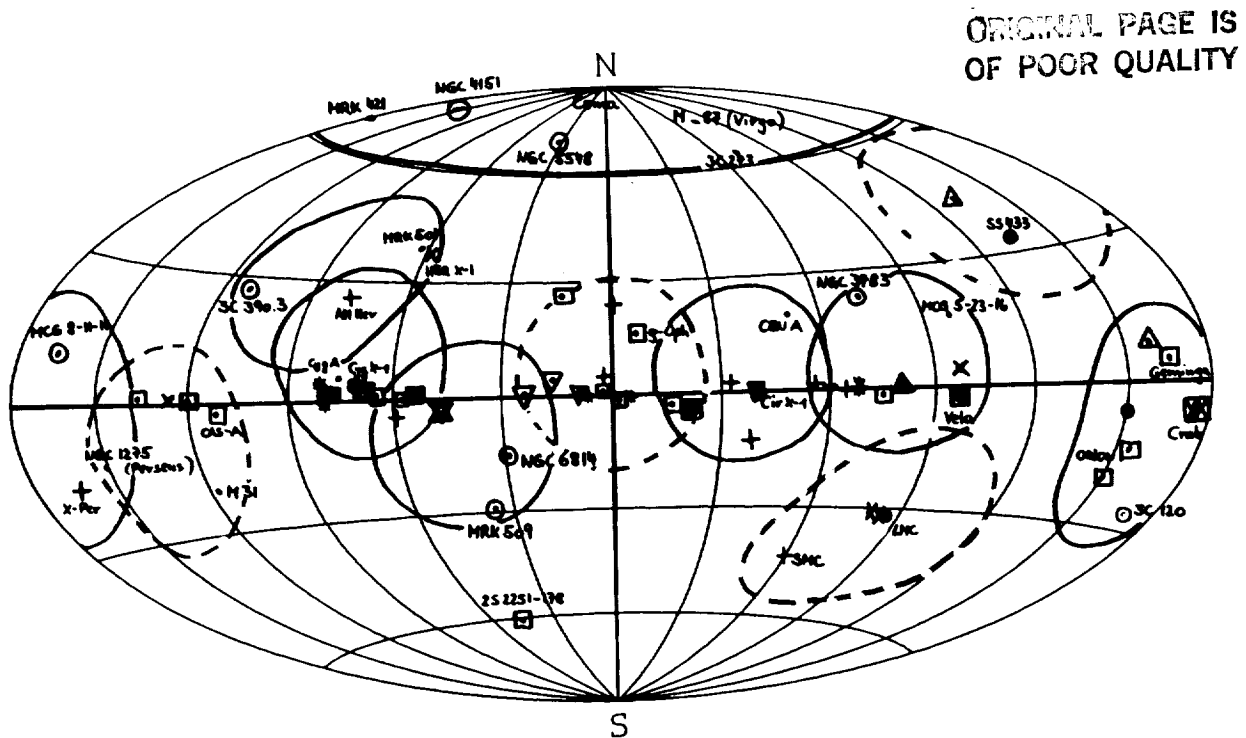


Figure 4. Suggested pointing directions during the second year of the GRO mission to perform an indepth observation of the most promising galactic and extragalactic objects (including of 16 objects of Table 2) which are covered by the 8 pointings marked by full circles (Steinle, 1989).

In order to improve the sensitivity of the AGN-observations it might be worthwhile to look longer towards them during the second year of the mission (e.g. for 28 days per target). If the pointing directions are selected carefully, a set of 8 pointings would be sufficient to include the 16 AGN's of Table 2.

The 16 objects and 8 possible pointing directions of the GRO spacecraft are shown in figure 4. A circle of 25° radius is drawn around each pointing direction indicating the field-of-view of COMPTEL during each observation. Since most of the pointing directions happen to be concentrated around the galactic plane, many galactic objects can be studied at the same time to quite same extent (like radio pulsars, X-ray binaries and other galactic objects). Indeed, by adding 4 more pointings (as indicated in figure 4) an indepth study of the most promising galactic and extragalactic objects can be accomplished in the second year of the mission.

I think that such a viewing strategy during the second year of the mission might also be of interest to EGRET; and if the exact locations of the viewing directions are selected carefully, it might allow OSSE to select proper secondary targets in addition.

For the understanding of AGN's it will be very important to make correlated observations at different wavelengths. As stated before, such observations have to be made simultaneously because of the time variability of the objects. I hope that we shall obtain quite a number of proposals for correlated observations during the GRO survey year in response to the NASA-Research Announcement.

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DISCUSSION

Carl Fichtel:

The material presented in the last two talks shows that the sensitivity of the GRO instruments should very likely allow a reasonably definitive answer to the question whether active galactic nuclei can explain the majority of the diffuse gamma radiation from both intensity and spectral viewpoints.

Volker Schonfelder:

Yes, I agree with you. This is a very important issue. If there really is a contribution of unresolved active galactic nuclei to the cosmic bodyground, then we can subtract this component from the measurements, and we shall see whether a really diffuse component is left over, and what spectral shape it has.

Darryl Leiter:

Could COMPTEL detect temporal (1 hour) variability in the diffuse gamma-ray background at $E \sim 1\text{-}3$ MeV, possibly due to Seyfert galaxies.

Volker Schonfelder:

The detectability will depend on the level of variability. The determination of the diffuse cosmic gamma ray background is probably the most difficult one of all GRO measurements. It will only be possible in the late part of the mission, after we have studied variations of the instrumental background and after we have learned how to extract cosmic gamma ray sources (point like and extended) from our data. If the variations in the diffuse cosmic background which you are expecting are of the order of a few percent or higher, we might be able to see them.

